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RADIOTELEMETRY TRACKING AT LAKE CONWAY, FLORIDA.(U)

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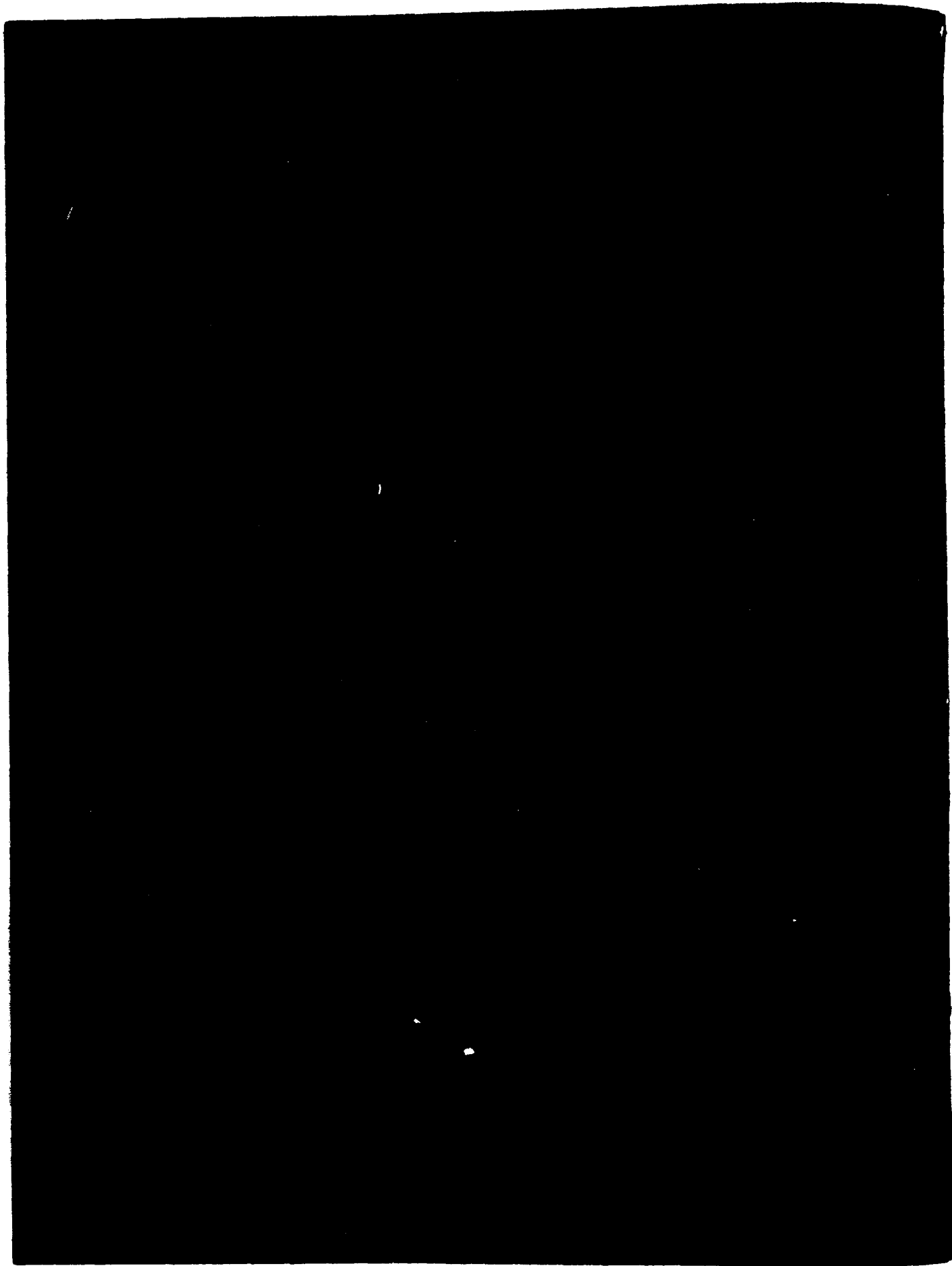
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20. ABSTRACT (Continued).

indicated a definite reduction of aquatic plant populations due to the fish's presence. What could not be determined from these observations was a correlation between fish movement within the lake system and the decline of the plants as a function of time. The examination of this problem indicated that radiotracking fish movements at comparable time intervals to the other data-collection efforts would provide the needed information. A mobile unit was assembled by WES at Lake Conway in May 1979 for tracking radiotagged fish. Since then more than 50 white amur have been tagged and tracked.

Cumulative siting data for 1484 observations made between 15 May 1979 and 15 October 1980 indicated that the radiotagged amur were present in vegetated areas over 90 percent of the time with the exception of the months of August and September when the amur were found in these areas 65 and 58 percent of the time, respectively. During the same period, divers observed progressive clearing of aquatic plants in the vegetated areas where the amur were concentrating. Radiotagged fish were often observed swimming with schools of approximately 30 untagged fish, indicating that tagged fish movement is similar to that of the untagged population.

Beginning in November 1979 some 75 individuals representing the resident herpetofaunal species were tagged and tracked with the same mobile unit used for locating the tagged white amur.

Preliminary findings through June 1981 have indicated that the *Chrysemys* and stinkpot turtles have very large home ranges and often travel distances greater than 1 km in a day or two. Most of the adult *Chrysemys* spp. spend their time in open water and rarely frequent the shallows. Tagged mud turtles generally remained in a 10- by 10-m area during the entire study period.

The WES also investigated methods to determine the depth of a radiotagged individual as well as its location.

Two approaches were field tested by WES. One approach evaluated the use of a receiving antenna positioned above the water surface. Severe signal fading cast doubt over the validity of the depth estimates. Examination of the test data and the theory underlying the propagation of a radio signal through a two-medium path indicated that the fading was probably a result of scattering of the signal across the air/water interface, the estimate of signal attenuation across the interface, or reflection of the tag signal from the lake bottom. The second approach (with the receiving antenna underwater) produced more favorable results, however the accuracy of the depth estimate could be further significantly improved by developing an antenna array with greater angular resolution.

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## PREFACE

Funds for the studies described herein were provided to the U. S. Army Engineer Waterways Experiment Station (WES) Aquatic Plant Control Research Program (APCRP) through the Department of the Army Appropriation No. 96X3122, Construction General, by the Civil Works Directorate, Office, Chief of Engineers, Washington, D. C., and through appropriation 96X4902, Operations and Maintenance, by the U. S. Army Engineer District, Jacksonville.

This report describes the development and field testing of a radiotelemetry tracking system used to locate white amur. This effort was conducted as part of the Large-Scale Operations Management Test at Lake Conway, Florida.

Messrs. Malcolm P. Keown and Robert M. Russell, Jr., Environmental Assessment Group (EAG), Environmental Resources Division (ERD), Environmental Laboratory (EL), WES, conducted the project and wrote this report. Ms. E. Mae Causey (EAG) prepared the appendices.

All phases of this study were conducted under the direct supervision of Mr. Jack K. Stoll, Chief, EAG, and the general supervision of Drs. Conrad J. Kirby, Chief, ERD, and John Harrison, Chief, EL. The manager of the APCRP at WES was Mr. J. Lewis Decell.

Special acknowledgement is made to Messrs. J. Steve Godley, University of South Florida; David L. Leese, Instrumentation Services Division, WES; Jerry R. Lundien, Environmental Systems Division, EL, WES; Larry E. Nall, State of Florida Department of Natural Resources (DNR); Thomas J. Pokrefke, Jr., Hydraulics Laboratory, WES; Anthony M. B. Rekas, EAG; and Jeffrey D. Schardt, DNR; without whose assistance the objectives of this project could not have been successfully met.



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Commanders and Directors of WES during the conduct of this project were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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## RADIOTELEMETRY TRACKING AT LAKE CONWAY, FLORIDA

### PART I: INTRODUCTION

#### Background

1. The U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., is responsible for conducting the Corps' Aquatic Plant Control Research Program (APCRP). Through the APCRP, research is being performed to develop environmentally compatible methods for controlling problem aquatic plants. More specifically, this research effort will result in methods that are either biological, chemical, or mechanical in nature or some combination of these three basic types of controls. A Large-Scale Operations Management Test (LSOMT) was initiated in 1976 at Lake Conway, Florida, to evaluate the use of the white amur fish (*Ctenopharyngodon idella*) as a biological method for the control of excessive aquatic plant growth (Decell 1976; Addor and Theriot 1977). Studies conducted prior to the LSOMT have shown that the white amur (Figure 1) is capable of controlling the growth of aquatic plants



Figure 1. The white amur is native to eastern Asia but has been introduced into various other parts of the world, both as a food fish and for controlling aquatic plants. Another common name for the white amur is "Asian grass carp," which indicates its natural preference for a vegetative diet. From all available evidence, including experimental pond studies, the amur is exclusively vegetarian

(Michewicz, Sutton, and Blackburn 1972); however, data have been lacking from which to draw substantiated conclusions regarding environmental compatibility or operational use. The Lake Conway LSOMT was designed to provide these data.

2. Lake Conway is located just south of Orlando, in Orange County, Florida. The LSOMT site is not a single lake, but a chain of five pools (Figure 2) with a single inlet and outlet. Preliminary surveys indicated that Lake Conway's simple flow regime was particularly

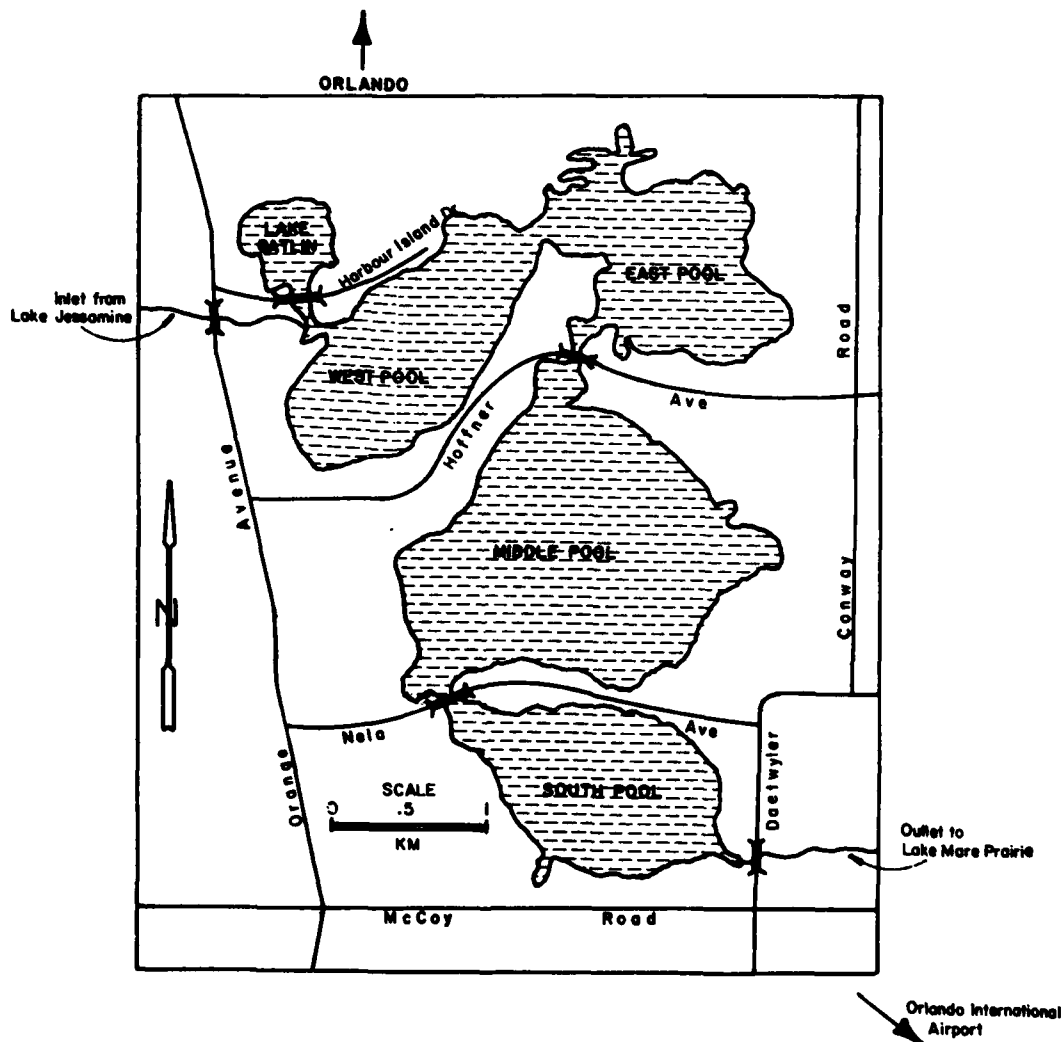


Figure 2. Chain of pools that forms Lake Conway

well suited for a controlled experiment because only two fish retention structures would have to be constructed to prevent the white amur from escaping into adjacent streams and lakes (a third structure was built downstream from the outlet structure as a backup measure). The surface area of the pools covers 7.6 km<sup>2</sup> with the maximum depth varying from 8 to 12 m among the five pools. The shoreline of Lake Conway is almost completely developed as a residential area, and, as a consequence, all of the pools are used intensively for swimming, fishing, skiing, and pleasure boating. In the early 1970's, the rapid growth of aquatic plants became a serious nuisance to these recreational activities. Prior to the LSOMT, 10 to 20 percent of the surface area was clogged. Local interests attempted to clear the plants from the surface by frequent spot spraying with herbicides; however, this approach provided only short-term relief from the infestation.

3. Lake Conway was stocked with 7000 white amur in September 1977. Aquatic plant sampling operations conducted by the State of Florida Department of Natural Resources (DNR) over the following 12 months indicated that a definite reduction in the plant population was taking place. What could not be determined from these observations was a correlation between fish movement within the lake system and the decline of the plant population as a function of time. The examination of this problem showed that mapping fish movements at comparable time intervals to the other data-collection efforts would provide the needed information. Further investigation indicated that the mapping could possibly be accomplished using ultrasonic or radiotelemetry tracking techniques, although both approaches were considered experimental.

#### Objectives

4. The objectives of this project were as follows:
  - a. Conduct a feasibility study to determine if ultrasonic or radiotelemetry techniques could be used to track white amur.

- b. Develop a tracking system for use at Lake Conway if the results of the feasibility study indicated that ultrasonic or radiotelemetry techniques could be used to track the white amur.
- c. Develop accurate and time-efficient methods to locate the tagged fish using the tracking system. The tracking data could then be used to map fish movements through the lake system.

5. Parallel with the aquatic plant sampling and white amur tracking efforts at Lake Conway, the University of South Florida (USF) initiated a study to evaluate the impact of the introduced white amur on the resident herpetofaunal community. A major part of this effort was the development of a typical movement history for the predominant herpetofaunal species such that variations in these movement patterns could be detected as the amur reduced the amount of available vegetation. During the initial phase of this study, 200 adult *Chrysemys* spp. (turtles) were marked and released; of these, only two were recaptured. This led to the conclusion that radiotagging and tracking of several individuals would considerably enhance the final product of the herpetofaunal study. Thus, as an additional project objective, the WES Environmental Assessment Group was assigned the task of modifying the Lake Conway tracking system to accommodate the herpetofaunal study.

## PART II: FEASIBILITY STUDY

6. Prior to the commitment of manpower and resources to a major tracking effort at Lake Conway, a feasibility study was conducted from May through September 1978 (Keown 1978). This study consisted of the following elements:

- a. Conduct a literature survey.
- b. Determine whether ultrasonic or radiotelemetry techniques would best be suited for tracking at Lake Conway.
- c. Conduct a preliminary field exercise to identify the major problem areas that would possibly be encountered if a tracking effort were to be initiated at Lake Conway.

### Literature Survey

7. A survey of literature sources related to tracking aquatic animals using ultrasonic\* and radiotelemetry techniques was initiated at the beginning of the feasibility study and has continued through preparation of this report. The references have been categorized into either ultrasonic or radiotelemetry sources and are listed in Appendixes A and B, respectively.

### Ultrasonic and Radiotelemetry Tracking

8. In December 1956, two scientists of the National Marine Fisheries Service released a 3.2-kg Coho salmon (*Oncorhynchus kisutch*) carrying a 132-kHz ultrasonic tag on its back. The salmon was tracked across a Seattle lake for slightly over an hour before failure of the receiving equipment ended the experiment (Monan, Johnson, and Esterberg 1975). This activity was the first reported attempt to track an individual fish using either ultrasonic or radiotelemetry techniques.

9. Ultrasonic signals travel through water as mechanical waves vibrating in an elastic medium. The major detriments to propagation of

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\* Frequencies above 20 kHz are considered to be ultrasonic; the normal human hearing response range is 20 Hz to 20 kHz.

an underwater ultrasonic wave are natural and man-made noise sources and signal absorbers. Natural and man-made noise sources tend to raise the background noise level and thus reduce the working range between an ultrasonic tag and an underwater receiving hydrophone. Typical noise sources are turbulence due to rapids or flow past structures, wave action, motorized vessels, air bubbles, raindrops striking the water surface, etc. Material in the propagation path can absorb (or reduce the amplitude of) an ultrasonic signal which also in effect reduces the working range of an ultrasonic tracking system. Typical absorbers are aquatic vegetation, ice, and zones of rapid temperature change.

10. Most of the ultrasonic tracking work has been done in the 30- to 300-kHz range. The optimum frequencies have been experimentally determined to be 70 to 80 kHz, where noise and signal absorption are less of a problem than at other frequencies. Ultrasonic tracking systems are not influenced by the electrical conductivity of water and thus can be used in high conductivity environments such as seawater (50,000  $\mu\text{mhos/cm}$ ).

11. The first use of radiotelemetry techniques for underwater tracking was reported in 1967 (Lonsdale 1967 and Soma et al. 1967). This approach for locating various underwater species was largely an outgrowth of terrestrial tracking. Radiotelemetry tracking work in aquatic environments has been conducted using frequencies ranging from 27 to 164 MHz. The two dominant factors affecting the propagation of radio signals through water in this part of the electromagnetic spectrum are the electrical conductivity\* of the propagation medium (water) and the radiation efficiency of the underwater antenna. The value of electrical conductivity is dependent on the quantity of electrolyte present and the transmission frequency; an increase in either parameter raises the conductivity. The effect of an increase in conductivity is to shorten the propagation path length over which communications can be maintained for a given transmitter/antenna and antenna/receiver configuration. Conversely, as the frequency is raised, the dimensions of the antenna in a

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\* Conductivities less than 1000  $\mu\text{mhos/cm}$  are considered suitable for underwater radiotelemetry tracking.

radiotag become larger with respect to the transmission wavelength, thus increasing the radiation resistance of the antenna, which in turn promotes a more efficient transfer of energy from the antenna to the propagation medium. Because of these opposing factors, a trade-off must be made to establish an optimum operating frequency. Experiments have shown that the use of frequencies in the 30- to 50-MHz band present a good compromise between the high conductivities experienced at short wavelengths and the improvement in antenna radiation efficiency that results when a shorter wavelength is used.

12. The electrical conductivity of the water in the Lake Conway pools has been monitored by the Orange County Pollution Control Commission since 1970 (Kaleel 1981). During this period, the conductivity has averaged 235  $\mu\text{mhos/cm}$  at the upper end of the lake system to 215  $\mu\text{mhos/cm}$  at the outlet which are typical values for a freshwater lake (these values were measured with a zero frequency or direct current (DC) device). The conductivity values measured at Lake Conway generally do not vary with depth. Thus, considering only the electrical conductivity of the Lake Conway water, either an ultrasonic or radiotelemetry system could be used for underwater tracking; however, considering the high potential for acoustic noise due to wave action and recreation activities and the large number of radio spectrum allocations available for experimental use as compared to the relatively limited ultrasonic spectrum, radiotelemetry was chosen as the more suitable technique for tracking at Lake Conway.

#### Preliminary Field Exercise

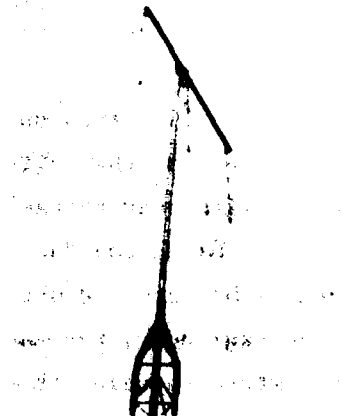
13. The components for a radiotelemetry tracking system were purchased from AVM Instrument Co., Champaign, Ill. These components included a Model LA-12 49-MHz receiver, a three-element Yagi antenna, and four radiotags suitable for fish implantation. Using these components, a preliminary field exercise was initiated with the following objectives:

- a. Determine the working range and maximum detection depth for the AVM radiotags.
- b. Assemble and test a mobile tracking unit.
- c. Track radiotagged fish with the mobile unit.

14. Tests to determine the working range and maximum detection depth for the AVM radiotags were conducted at Browns Lake (located on WES property) and at Lake Park (5 miles (8 km) south of WES) where the electrical conductivities of the water were 1700 and 180  $\mu\text{mhos/cm}$ , respectively. Conductivity values were measured at the surface and at a depth of 1 m with a Markson Portable Conductivity Meter (Model 10). Examination of these data indicated that the conductivity was relatively constant over both lakes, both at the surface and at 1 m deep. Note that the Markson Meter measures conductivity as a DC value (zero frequency), which may or may not reflect the true 49-MHz conductivity; thus, the results reported herein should be used for comparative purposes only when underwater radiotracking experiments are conducted at 49 MHz.

15. A receiving station was set up on the earth embankment at the deep end of each lake using the Yagi antenna in a vertically polarized configuration (Figure 3). The working range and maximum detection depth

Figure 3. Yagi receiving antenna used to determine working range and maximum detection depth for the AVM radiotags





were determined by attaching each tag to a depth-calibrated rope that was lowered from a johnboat positioned at a known horizontal distance from the receiving antenna. The maximum depth that the signal was detectable was recorded, thus establishing the maximum detection depth for a given horizontal distance between the tag and receiving antenna. The results were practically identical for all tags tested. Best fit lines are plotted for the resulting data in Figure 4; in addition, the data provided in the AVM product literature are plotted. Figure 4 shows that, as the electrical conductivity of the water increases, the maximum depth of detection decreases for a given horizontal distance between the antenna and underwater tag. The conductivity at Lake Park was nearly the same value as the conductivities measured at Lake Conway (paragraph 12); thus, a working range at Lake Conway of at least 1000 m at a 1.5-m depth could be anticipated using the same equipment.

16. A mobile tracking unit was assembled at Lake Park using the johnboat, the AVM LA-12 receiver, and a Dav-Tron Model MLA circular receiving loop (Figure 5). Testing of this unit for tracking purposes indicated that the directivity of the loop antenna was poor; i.e., signal sources were very difficult to locate with less than a 45-deg azimuthal error. An improved tracking unit was developed by mounting a tripod tower (3 m in height) in the johnboat (Figure 6). The tower was stabilized by bolting the legs to a piece of plywood positioned in the bottom of the boat and by attaching a guy wire from each tower leg to the bow and to either side of the stern. A mast 5 m in height was then positioned on a thrust bearing (bolted to the piece of plywood) and extended through the tower apex collar. A three-element vertically polarized Yagi antenna was then attached to the mast and connected to the LA-12 receiver with coaxial cable (Figures 6 and 7).

17. Using the Yagi array, the azimuth to a signal source (radio-tagged fish) from the mobile tracking unit could be determined by rotating the Yagi until the maximum deflection was obtained on the receiver's signal strength meter (Figure 7). The boom of the antenna (horizontal member) was then pointed towards the signal source. Assessment of the

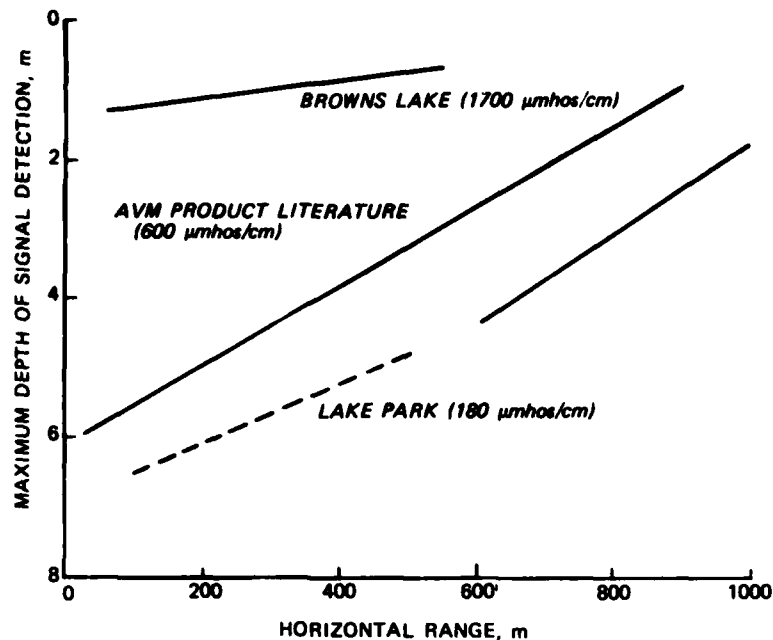


Figure 4. Maximum depth that radiotag signal was detectable for given horizontal distance between tag and antenna. Conductivities are shown in parentheses. The dashed portion of the Lake Park curve indicates that the bottom of the lake was reached before the signal strength became less than the receiver's noise floor; thus, the depth shown represents a conservative estimate of the maximum depth. The effective radiated power of the 49-MHz radiotags was estimated to be less than -70 dbm. All conductivities were measured with a DC instrument



Figure 5. Tracking with a circular receiving loop



Figure 6. Tripod tower mounted in johnboat with Yagi antenna attached to mast

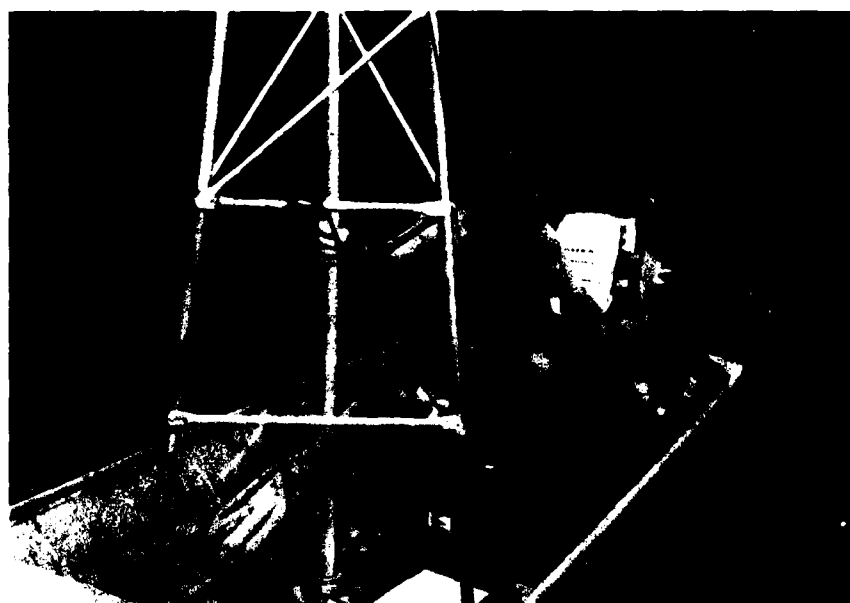


Figure 7. Operator determines azimuth to radiotagged fish by rotating antenna mast until maximum signal strength is obtained on the LA-12 signal strength meter. Note that the mast is rotated on a thrust bearing bolted to a piece of plywood positioned in the bottom of the boat

accuracy of this system indicated that a typical azimuthal error of 15 deg could be anticipated.

18. The final task of the preliminary field exercise was to radiotag one or more fish native to the Lake Park reservoir and to track the fish for a 5-week period. Two carp (*Cyprinus carpio*) were captured with a gill net on 22 August 1978. The fish were held for 3 to 4 hr after capture in 75-l plastic garbage cans that had been weighted and sunk in shallow (1 m) water along the shore. Eight to twelve 2-cm-diam holes had been cut in each can to allow water circulation. The observation period was necessary to determine if the gill-netting capture method would result in the death of the fish. No fatalities were experienced. After the observation period, each fish was transferred to a 75-l plastic garbage can containing 15 ppm quinaldine in 40 l of lake water. The fish remained in the water until completely anesthetized (turned belly up). Once anesthetized, the fish were placed in a shallow (10-cm depth) pan with enough water to keep the gills submerged. A 4-cm incision was made through the abdominal wall (between the pelvic and anal fin) into the body cavity; a radiotag was then inserted into the cavity (Figure 8). The incision was sewn closed with 10-kg test black



Figure 8. Insertion of radiotag into fish body cavity. The tag is being passed from the assistant into the right hand of the scientist. The forefinger of the scientist's left hand is inserted into the incision

braided nylon fishing line. To prevent infection from the surgery, each fish was injected near the incision site with 4.4 cc/kg of a sterile saline water solution containing 50 mg/ml tetracycline IM (Achromycin for human intramuscular injection with 2 percent lidocaine). The fish were held 12 hr after the surgery for observation in the sunken garbage cans, after which they were released.

19. The locations of the radiotagged fish were determined by triangulation. The mobile tracking unit was sited at a known position shown on a map of the lake (Figure 9) and the azimuth towards a tagged fish determined by rotating the Yagi until the maximum signal strength was obtained (paragraph 17). After the azimuth was determined, a line was laid out on the map from the position of the mobile tracking unit

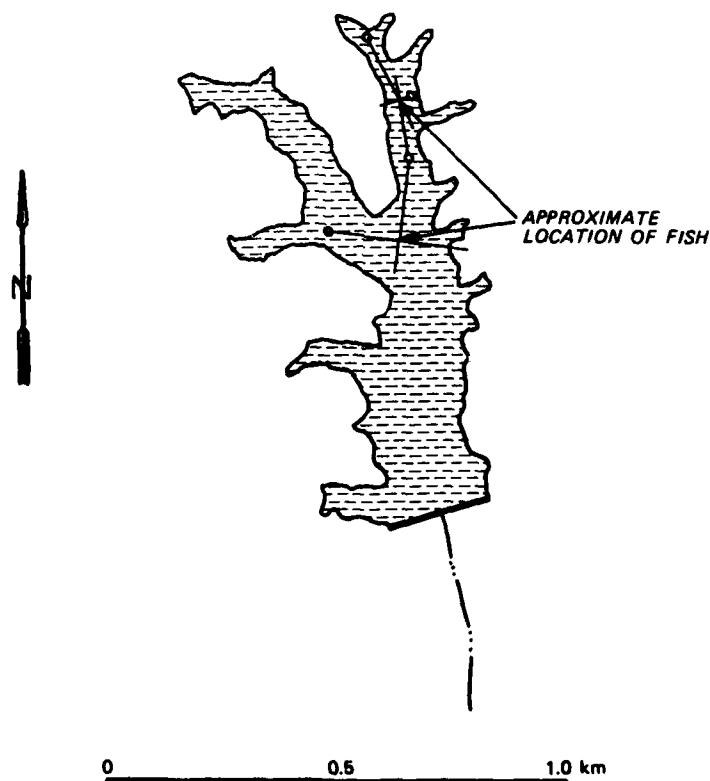


Figure 9. Sample triangulation to determine approximate location of two radiotagged fish at Lake Park. Small circles represent mobile tracking unit locations

toward the location of the radiotagged fish. The tracking unit was then moved to another position where the azimuth towards the fish was again determined and a line placed on the map. The intersection of the two lines then indicated the approximate location of the fish. The two carp were tracked until 3 Oct 1978.

20. Based on the positive results of the feasibility study, a recommendation was made to the Program Manager of the APCRP to consider radiotelemetry as a method to collect the data needed to establish a correlation between white amur movement in Lake Conway and the decline of the aquatic plant population as a function of time. This recommendation was accepted and funding was made available to include a radiotelemetry tracking system as part of the work under the Lake Conway LSOMT.

### PART III: DEVELOPMENT OF RADIOTELEMETRY TRACKING SYSTEM

21. The radiotelemetry tracking system used to locate white amur at Lake Conway was developed in two phases. The first phase included the procurement and implantation of radiotags; the second phase, which was in progress at the same time as the first phase, was construction of the mobile tracking unit.

#### Fish Radiotags

22. Fish tracking technology has moved rapidly forward over the past few years. In 1970, radiotag design life was a matter of a few days; by 1975, commercially available tags could be purchased with design lives measured in terms of weeks; now tags have advertised lives in excess of 5 years. The tags used at Lake Conway were obtained from two sources. The first set (35 tags) was purchased from AVM Instrument Company, Champaign, Ill., in April 1979 (Figure 10). These tags were



Figure 10. AVM Instrument Company fish tag. The antenna loop is on the left end of the tag, the transmitter in the center, and the battery on the right end. This tag was implanted in November 1979 and recovered after the fish died. The crack at the base of the antenna loop was probably caused by pressure of the internal organs against the loop

11 cm in length, 3 cm in diameter, weighed 61 g (less than 1 percent of the total weight of the fish in which they were implanted), and operated on crystal-controlled frequencies between 49.6 and 50 MHz. Each tag transmitted on a different frequency, so that once implanted each tagged fish would have a unique identity. The electronic circuit of the tags consisted of a lithium battery that supplied power to an oscillator. This oscillator was then coupled to a loop antenna.

23. The oscillators operated in a pulse mode; i.e., they were controlled by a triggering circuit that allowed transmission only during a very short part of the duty cycle. This design feature considerably lengthened the life of the tag. Although the power input of the AVM tags used at Lake Conway was approximately one-tenth of a milliwatt, the effective radiated power of the tags was much less (estimated to be -70 dbm) because of the poor radiation efficiency of the antenna. The tags were put on-the-air by removing a magnet taped to the tag; when the magnet was removed, an internal reed-switch closed, thus activating the oscillator.

24. The second set of radiotags (29) was purchased from Wildlife Materials, Inc., Carbondale, Ill., in November 1980 (Figure 11). These



Figure 11. Wildlife Materials, Inc., fish tag. Note the bar magnet over the antenna loop; when this magnet is removed, a reed switch closes which activates the oscillator



tags were 11 cm in length, 3 cm in diameter, and weighed 70 g. The electronic circuitry of both the AVM and Wildlife Materials tags was similar; the major difference between the tags was the mechanical construction. Several implanted AVM tags were recovered after the fish died. Many of these tags were broken at the base of the antenna loop as shown in Figure 10. Submersion of the recovered tags in water eventually led to transmitter failure, leading to the conclusion that some implanted tag failures could probably be attributed to the same problem. As a result, the antenna loop of the Wildlife Material tags was completely encapsulated in acrylic (Figure 11) so that the base of the loop would be strengthened.

25. The radiotags were implanted by personnel of the DNR. A temporary holding facility was constructed on the shore of Lake Conway in front of the DNR field office to keep the fish prior to surgery and to observe them after tag implantation. The holding facility consisted of three 1200-l tanks equipped with a circulating pump that provided a lake water flow-through system. The fish were initially anesthetized in a 4-ppm quinaldine solution in one of the 1200-l tanks. This aided in handling during weighing and transfer to the surgical tank, which consisted of a V-shaped trough in an aerated 80-l aquarium. The trough allowed positioning of the fish ventral side up with the gills submerged. The concentration of quinaldine solution used in the surgical tank ranged from 4 to 15 ppm, depending on the amount necessary to prevent fish movement.

26. Once anesthetized, two or three rows of scales were removed around the incision site. A 5- to 7-cm incision was then made vertically just anterior to the pelvic fin girdle. The lower end of the incision terminated 2 to 3 cm from the midventral line. This incision site was chosen over a longitudinal midventral incision because the tag and viscera would probably place a strain on the sutures of a longitudinal incision and thus possibly open the wound.

27. The tag was implanted into the abdominal cavity and positioned at the lowest point (Figure 12). Incision closure was accomplished using 000 Type C Chromic Gut suture material. Four to six



Figure 12. Radiotag being implanted into white amur  
(photo courtesy of the State of Florida Department  
of Natural Resources)

deep stitches were made through the body wall using a 6-D half-circle cutting suture needle. Five to seven shallower stitches were then made through the epidermis using a smaller 8-D half-circle cutting needle, which ensured a tight closure. After completion of the closure, 10 ml of injectable Terramycin solution, which contained 50 mg/ml oxytetracycline hydrochloride, was administered intramuscularly. This represented a dosage of approximately 55 mg of oxytetracycline per kilogram of body weight. Further details on the procurement of the white amur, the implantation procedure, and postoperative observations are described in documentation prepared by DNR (Nall and Schardt 1980; Schardt and Nall 1981; and Schardt, Nall, and Jubinsky, in preparation).

#### Mobile Tracking Unit

28. The mobile tracking unit was constructed on a pontoon boat with a 2.5- by 5-m aluminum deck. The antenna array was supported with

a guyed Rohn 25AG tower top section (Figure 13). The weight of the array rested on a Rohn TB3 thrust bearing mounted inside the tower section (Figure 14). The array was turned with a manually operated gear and worm-drive rotator that was specially fabricated at WES (Figure 14). A small operator's desk was constructed and attached to the aluminum deck near the tower section (Figure 15); from this position the operator could rotate the antenna array and make adjustments to the telemetry receiver (AVM LA-12) (Figure 16).

29. The antenna array consisted of two vertically polarized three-element Yagis (Figure 13). The array was constructed with the proper switching circuitry to have either a null or a peak in the radiation pattern; that is, when the Yagi transmission lines are the same length, the signals are additive resulting in a 3-db gain over a single Yagi. When a half-wave section is added to one of the transmission lines, the signals are 180 deg out of phase with each other resulting in a null in the array radiation pattern.\* The peak azimuth, which is determined by a maximum reading of the on-board receiver's signal strength meter, occurs at nearly the same azimuth as the azimuth toward a radiotagged fish from the mobile tracking unit (the null azimuth occurs at a minimum reading of the meter). The typical azimuthal error with the array's switching circuitry in the peak position is 10 deg or less and 3 deg or less in the null position. Thus, the general direction from the mobile unit toward a tagged fish can be determined with the array in the peak position, and once this azimuth is established, a more accurate reading can be made using the null position. The Yagis were spaced 4.9 m apart, which is the minimum separation allowable for the antennas to perform as a null-peak array.

30. The vertical clearance required for the antenna array was in excess of 5 m, which was considerably higher than the clearance under the bridges crossing the interconnecting canals between the pools (Figure 2). As a result, provisions had to be made in the design of the

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\* The switching was accomplished with a null-peak phasing unit as shown in Figure 16.

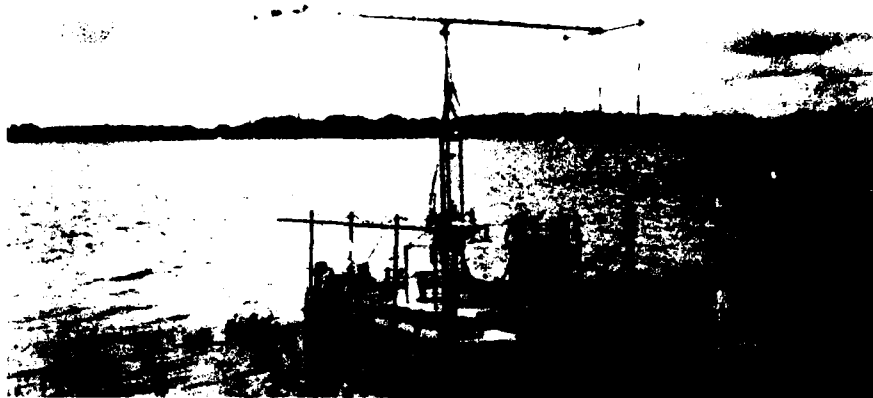


Figure 13. Mobile tracking unit at Lake Conway



Figure 14. Rohn TB3 thrust bearing and manually operated rotator mounted inside tower section



Figure 15. The operator's desk was positioned near the manually operated rotator so that the antenna array could be turned and the receiving equipment adjusted from the same position

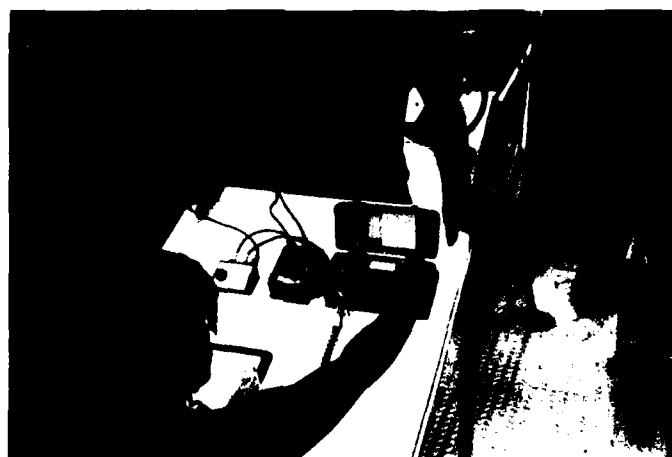


Figure 16. Operator's desk. The AVM LA-12 radiotelemetry receiver is shown on the right, the null-peak phasing unit in the center, and a coaxial switch on the left. The additional coaxial switch port was connected to a short vertical antenna that was occasionally used for monitoring signals at very short ranges

mobile tracking unit to lower the antenna array while the tracking unit was moving through the canals. To meet this requirement, the tower section was mounted on a hinged-base plate such that the entire tower and antenna array could be tilted forward when the guy wires were disconnected. An aluminum support structure was built on the bow of the tracking unit to nest the tower and antenna array while traveling through the canals.

31. Tests were conducted at Lake Conway in August 1979 to determine the maximum radiotag detection depth for given horizontal distances between the null-peak antenna array and five sample tags (AVM). The results are plotted in Figure 17. The peak line shown in Figure 17 compares favorably with the data taken at Lake Park in 1978 (Figure 4).

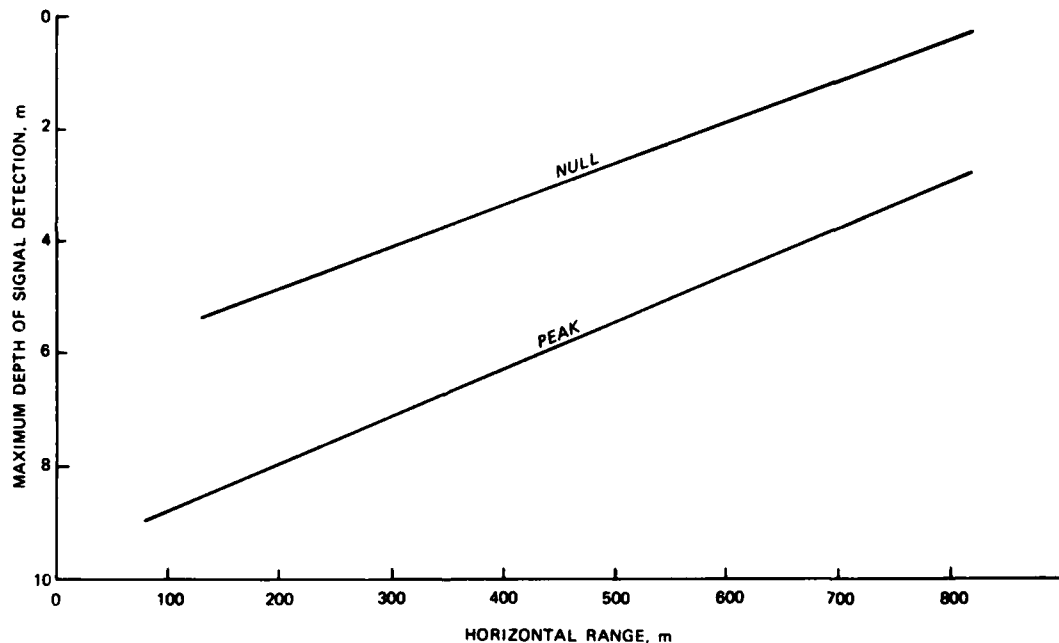


Figure 17. Maximum depth that radiotag signal was detectable for a given horizontal range between the tag and mobile tracking unit. The conductivity of the Lake Conway water was 230  $\mu\text{mhos/cm}$  (DC). The effective radiated power of the 49-MHz fish tags was estimated to be less than the -70 dbm

#### PART IV: RADIOTRACKING TAGGED FISH

32. The mobile tracking unit construction was initiated in March 1979 and continued through May 1979. Parallel with the completion of work on the tracking unit, ten white amur were implanted with AVM radio-tags and released. Tracking commenced in May 1979 and continued through December 1981. As the tracking work progressed, a better understanding was developed of signal propagation from a tag to an above-water receiving antenna; in addition, better methods for locating the surface position of a tagged fish were developed as a result of field experience.

##### Signal Propagation from an Underwater Radiotagged Fish to an Above-Water Receiving Antenna

33. As a radio signal travels away from an implanted tag\* toward an above-water receiving antenna, attenuation is experienced over three distinct parts of the propagation path: through the water, at the air/water interface, and through the air (Figure 18). The unit attenuation  $A_1$  through water (db/m) can be estimated from:

$$A_1 = 0.1635 \left( \frac{\sigma}{\sqrt{\epsilon_r}} \right) \quad (1)$$

where

$\sigma$  = electrical conductivity of water at the signal frequency,  
μmhos/cm

$\epsilon_r$  = dielectric constant of water (varies from 87 at 1.5°C to  
78 at 25°C for frequencies from 10 to 100 MHz)

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\* Velle (1979) demonstrated that there was very little change in the drive point impedance of an antenna in water ( $\sigma = 1320$  μmhos/cm) and the same antenna implanted in a fish; that is, the fish tissue did not seem to be affecting the antenna's performance. Experiments conducted as part of this study comparing the signal strength of an underwater tag with and without a human hand wrapped around the tag showed that there was no significant difference in strength. Thus, with this preliminary information, the tag's being in or out of a fish seemed to make no difference.

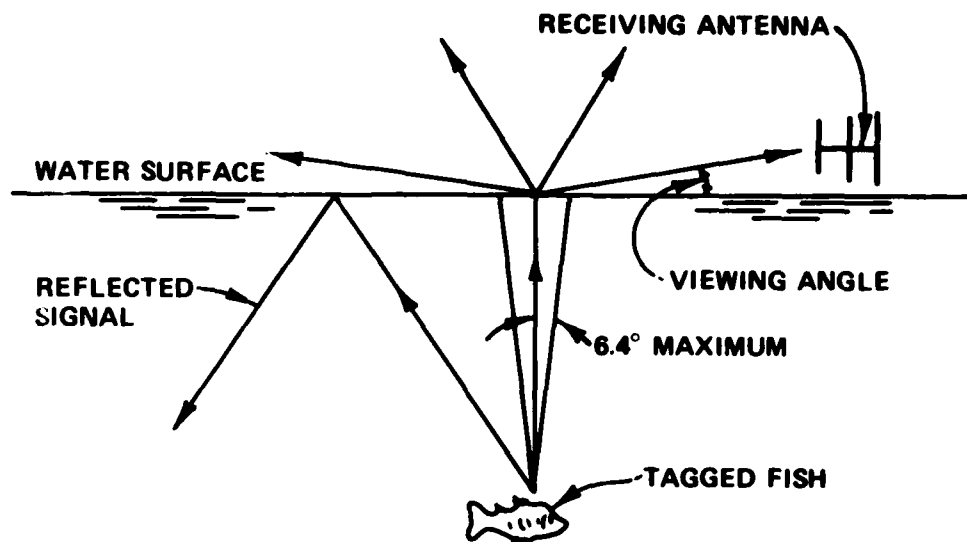


Figure 18. Signal propagation path between an underwater radiotagged fish and an above-water receiving antenna

As the radio signal approaches the air/water interface, only the portion of the incident signal that makes an included angle of 6.4 deg or less\* with the water surface normal is propagated across the interface (Figure 18). The remainder of the signal is reflected back into the water; thus, less than 0.5 percent of the power radiated from the tag is available to be transmitted across the interface, exclusive of the losses incurred due to water attenuation between the tag and the surface. Once the signal has crossed the interface, the remaining energy is distributed into vertically and horizontally polarized components spread through the radiation hemisphere.

34. The signal loss at the air/water interface is a function of the dielectric constant of the water and the viewing angle in air (Figure 18), i.e., the included angle between the water surface and the path between the source of radiation (the location on the water surface where the signal is being radiated from) and the receiving antenna. Measurements by other investigators have shown that this loss is 27 to 30 db

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\*  $\theta = \text{Arcsin} \left( \frac{1}{\sqrt{\epsilon_r}} \right) = \text{Arcsin} \left( \frac{1}{\sqrt{81}} \right) = 6.4 \text{ deg.}$



for viewing angles of 10 to 5 deg (Velle 1979 and Bussey and Larsen 1974). Once the signal has crossed the air/water interface, it suffers further attenuation through air until the receiving antenna is reached. This signal attenuation  $A_2$  (db) can be computed from:

$$A_2 = 22 + 10 \log_{10} \left( \frac{d}{\lambda} \right)^2 \quad (2)$$

where

$d$  = length of propagation path in air over which attenuation is being measured, m

$\lambda$  = wavelength of radio signal in air, m

#### Locating Radiotagged Fish

35. Since May 1979 more than 50 white amur have been tagged by DNR personnel. Two methods have been used to determine the surface location of the tagged fish: simple triangulation and the pursuit method. In triangulation, the location of the mobile tracking unit was determined by triangulating with at least three known points on the shoreline. An observation site and a compass rose attached to the mast of the antenna array were used to determine the relative angles between these known points. This location was then plotted on a pool map using a swing-arm protractor. The azimuth to a tagged fish from the mobile tracking unit was initially determined by rotating the antenna in the general direction of maximum signal amplitude with the Yagis in phase; the measured azimuth was then determined by switching in the 180-deg phasing line and then rotating the antenna until the null in the radiation pattern was obtained. The orientation of the antenna array was then the same as the azimuth from the tracking unit to the fish. This azimuth was laid out on the pool map from the previously plotted location of the tracking unit. After completing this procedure from at least three locations, the location of the fish was estimated to be at the intersection of the azimuths. Comparisons of estimated surface locations with known locations indicated that the error using the triangulation method ranged from 15 to 25 m.

36. The triangulation method of acquiring data using the null-peak array proved to be somewhat time inefficient. A quicker method was developed as a result of field experience. Using the second approach, the pursuit method, the antenna array was oriented broadside with the direction of travel of the mobile tracking unit (with the array in the peak position). The operator of the craft, using the on-board radio receiver,\* proceeded in the direction of maximum signal strength. As the tracking unit passed over the location of a tagged fish, there was a drastic reduction in signal strength; this reduction resulted from the fact that the front-to-back power ratio of the antenna array was in excess of 20 db. After passing over the fish, the tracking unit then circled back to the estimated position of the fish to verify the location. If the craft was maneuvered rapidly, the wake formed an "x" at the estimated location. Use of the mobile tracking unit in conjunction with the pursuit method has proven to be a reliable technique to determine the surface locations of tagged fish. Comparisons of estimated locations with known locations have indicated that the difference is generally less than 5 m. Since July 1979, the pursuit method has almost been used exclusively for tracking tagged fish.

#### Preliminary Results

37. Cumulative siting data prepared by DNR (Figure 19) for 1484 observations made between 15 May 1979 and 15 October 1980 indicated that the radiotagged amur were present in the vegetated areas over 90 percent of the time with the exception of the months of August and September when the amur were found in the vegetated areas 65 and 58 percent of the time, respectively. During the same period, divers observed progressive clearing of aquatic plants in the areas where the amur were concentrating. Further, DNR observations indicated that the amur tended to stay in shallow waters; of the 1484 sitings, 93 percent were at locations

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\* The front of the desk shown in Figure 15 was turned toward the bow of the mobile tracking unit so that the operator could drive the craft and adjust the receiver simultaneously.

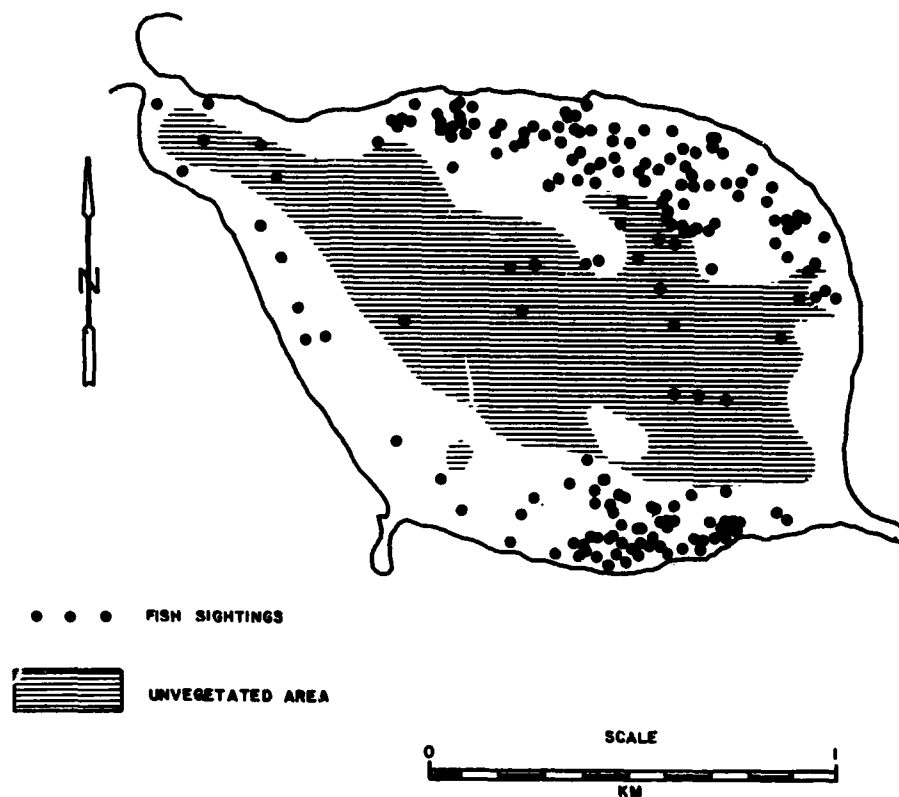


Figure 19. Cumulative radiotagged fish sitings in the Lake Conway South Pool from 15 May 1979 through 15 October 1980 indicated that the white amur were concentrating in vegetated areas

where the water was less than 3 m deep (Schardt and Nall 1981).

38. Examination of sequential sitings for various radiotagged individuals showed that the fish demonstrate a wide variation in behavior. Some fish remain in a given area for a period of time and then move to a new location; others regularly move between the same locations, while still others tend to wander. Radiotagged fish were often observed swimming with schools of approximately 30 untagged fish, indicating that tagged fish movement is similar to that of the untagged population (Schardt and Nall 1981). None of the tagged fish crossed from South or East Pool into Middle Pool (Figure 2) during the course of the study (based on observations through October 1980). The shallow, narrow

canals connecting these pools may have been sufficiently restrictive to prevent travel between the pools; however, the fish routinely crossed between East and West Pools. This opening is 4 m deep and about 50 m across, and apparently not restrictive to passage. No tagged fish were released in Lake Gatlin and none were sited in this pool.

39. Twenty-six AVM radiotags were implanted by DNR between 3 May and 18 December 1979. Of these 26 tags, 4 have continued to operate through the present (June 1981). These tags have been "on-the-air" 787, 785, 683, and 559 days, respectively. The other 22 tags are no longer active due either to an electronic malfunction or fish death; DNR attributes at least part of the electronic failures to a crack at the base of the antenna loop (paragraph 24), which probably admitted fluid into the transmitter circuitry. The maximum operational life of the failed tags was 414 days and the minimum was 6 days; the average life was 186 days. Twenty-four Wildlife Materials tags have been implanted since December 1980; none of these tags have failed to date (June 1981). At the conclusion of this study, the radiotelemetry tracking data and the remainder of the LSOMT findings will be used to determine whether the introduction of white amur into a water body infested by aquatic plant growth is an environmentally compatible operational control method in conditions such as those found at Lake Conway.

## PART V: HERPETOFAUNAL STUDY

40. Parallel with the DNR aquatic plant sampling and white amur tracking efforts, USF initiated a study to determine the impact of the introduced white amur on the resident herpetofaunal community (Godley, in preparation). A major part of this effort was the development of a typical movement history for the predominant herpetofaunal species such that variations in these movement patterns could be detected as the amur reduced the amount of available vegetation.

41. During the initial phase of this study, 200 adult *Chrysemys* spp. (peninsula cooters and Florida red-bellied turtles) were marked and released; of these, only 2 were recaptured. This led to the conclusion that radiotagging and tracking of several individuals would considerably enhance the final product of the herpetofaunal study.

### Modification of Mobile Tracking Unit

42. Analysis of the project funding schedule indicated that herpetofaunal radiotagging would be economically feasible only if the existing mobile tracking unit could be utilized. In the fish-tracking study, the dual Yagi antenna array was resonated at 49.8 MHz (midpoint of the 49.61 to 49.99 band). Ideally, the herpetofaunal studies should be conducted on an adjacent band in order to avoid confusion of fish tag signals with herpetofaunal tag signals.

43. A band (46.61 to 46.99 MHz) was available 3 MHz below the fish-tracking band; however, in order to use the same mobile tracking unit (but with a different receiver), the resonant frequency of the dual Yagi antenna array would have to be shifted to 48.3 MHz in order to accommodate the frequency bands for both studies. The resonant frequency was lowered by lengthening the Yagi elements to dimensions calculated from conventional equations for a 48.3-MHz array. No apparent degradation in antenna performance was noted on either band as the result of the resonant frequency modification.

### Herpetofaunal Radiotags

44. The radiotags purchased for the herpetofaunal studies (Figure 20) are listed below:

Herpetofauna			Radiotag			
Species	Common Name	No. Tagged	Design Life months	Max Weight g	Max Dimension, cm	
					Diameter	Length
<i>Sternotherus odoratus</i> / <i>Kinosternon subrubrum</i>	Stinkpot/ Mud turtle	25	4	5.5	1.5	2
<i>Chrysemys floridana</i> / <i>Chrysemys nelsoni</i>	Peninsula cooter/ Florida red-bellied turtle	25	54	80†	3	10
<i>Chrysemys floridana</i> / <i>Chrysemys nelsoni</i>	Peninsula cooter/ Florida red-bellied turtle	5	15	40†	2	7
<i>Siren lacterina</i>	Aquatic salamander	15	15	15	1.7	3.5

† Male *Chrysemys* are generally smaller than the female and thus cannot carry an 80-g tag that would represent more than 5 percent of the average male *Chrysemys* body weight.

The electronic circuitry used in these tags was essentially the same as that used in the fish tags (paragraphs 22-23); 30 tags were purchased from AVM Instrument Company and 40 from Wildlife Materials, Inc.

45. The stinkpots, mud turtles, and *Chrysemys*\* were tagged by fixing the tag to the rear of the shell with dental acrylic and monofilament line (Figure 21). The line was considered to be a necessary

\* The Peninsula cooter and Florida red-bellied turtle are collectively called *Chrysemys*.



Figure 20. Wildlife Materials, Inc., herpetofaunal radio-tags used to track (from top to bottom) female *Chrysemys* turtles, male *Chrysemys* turtles, aquatic salamanders, and stinkpot/mud turtles (photo courtesy of the University of South Florida)

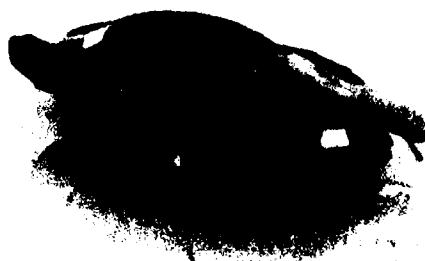


Figure 21. Radiotag attached to female *Chrysemys* turtle with dental acrylic and monofilament line

backup for the acrylic because turtles often shed epidermal scutes (parts of their shell surface). The monofilament line was tied from holes drilled in the tags to holes drilled along the perimeter of the shell.

46. The salamanders were tagged by internal implantation. The general method used for the implantation was to anesthetize the individual with chlorotone, insert the tag through an incision into the body cavity, and suture the incision (Figure 22).



Figure 22. Implantation site for aquatic salamander (photo courtesy of the University of South Florida)

47. The design life for the battery used in the stinkpot/mud turtle tags was only 4 months (because of maximum tag weight considerations); thus, the batteries had to be field replaced on a regular basis if the time-history of an individual was to be continued past 4 months. This requirement necessitated being able to locate the position of a tagged individual with an error of much less than 5 m. The USF researchers found that using a single Yagi array\* in a johnboat provided

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\* This array was identical to the array used at Lake Park (paragraphs 13-19).



a rapid method to locate the general vicinity of the turtle within 20 m or less. If the turtle could not then be visually sighted, an insensitive loop antenna attached to a dip net could be used to locate and remove the turtle from the lake (Figure 23). The johnboat proved superior to the mobile tracking unit for this application because of improved mobility in very shallow water and the capability to travel through the interconnecting pool canals when the water surface elevation was low.

48. After locating and removing a tagged turtle from the lake, the acrylic around the battery compartment was dissolved with acetone; when the battery was exposed, it was removed and replaced with a fresh

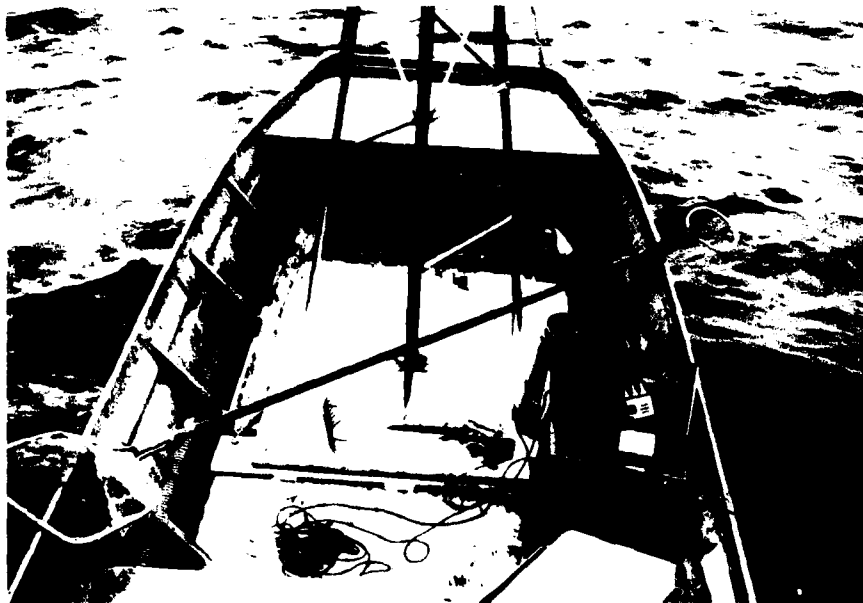


Figure 23. Insensitive hand-held loop antenna (on right end of dip net staff) used to locate the exact position of the small tagged turtles. Once this location was determined, the turtle could be removed from the water with the dip net for battery replacement, provided the turtle was not at a depth greater than 2 m (photo courtesy of the University of South Florida)

cell. Acrylic was then applied to restore the tag to its original condition. No apparent stress or damage was suffered by the turtles during this procedure. This method was found to be highly effective;

several turtles were recaptured six times for battery replacement.

49. The mobile tracking unit was used for locating radiotagged herpetofaunal species when individual recovery was not required. The null feature of the dual Yagi antenna system was particularly useful for this application; when the herpetofaunal species were near the shoreline, the antenna array was oriented perpendicular to the direction of travel (toward the shore). As the tracking unit moved along the shoreline, the various tagged individuals were located as their signals passed through the null of the antenna array's radiation pattern. When the tagged individuals were in open water, the pursuit method was used (paragraph 36).

#### Preliminary Results

50. Radiotracking by USF through June 1981 indicated that the *Chrysemys* spp. and stinkpot turtles have very large home ranges and often travel distances greater than 1 km in a day or two. Most of the adult *Chrysemys* spp. spend their time in open water and rarely frequent the shallows, thus explaining the low recapture rate for these species at permanent USF shoreline sites. On the other hand, the tagged mud turtles appear to be rather sedentary with some tagged individuals having remained in a 10- by 10-m area during the entire study period.

51. The 30 AVM Instrument Company herpetofaunal tags were used for the initial tagging in November and December of 1979. Of the 30 tags, 24 failed with an operational life less than their design lives. Forty additional individuals were tagged in December 1980 using tags purchased from Wildlife Materials, Inc. As of June 1981, three of these tags had failed. At the conclusion of this effort, USF will determine if any changes in herpetofaunal population or movement patterns can be directly attributed to the introduction of white amur into Lake Conway and the subsequent reduction in vegetation availability.

## PART VI: ESTIMATION OF RADIOTAG DEPTH

52. The procedures developed to locate radiotagged fish and herpetofauna with the mobile tracking unit and johnboat can only be used to determine the surface position of a tagged individual. As part of the radiotracking study at Lake Conway, an attempt was made by WES to develop a technique to estimate tag depth. The initial approach used to estimate depth accounted for all signal losses (and gains) along the propagation path between the underwater radiotag and an above-water antenna and receiver. The second approach also accounted for signal losses (and gains) along the propagation path, but differed from the first method in that the receiving antenna was positioned below the water surface.

### Estimation of Radiotag Depth Using an Above-Water Receiving Antenna

53. If the effective radiated power of a radiotag is known, in addition to the signal losses across the air/water interface and through the air, the gain of the receiving antenna, the loss in the transmission line between the antenna and receiver, and the signal noise floor of the receiver,\* then the only unknown along the signal propagation path is the attenuation between the tag and water surface. This attenuation  $A_w$  (db) can be computed as follows:

$$A_w = P_L - S_L - A_2 + Y_G - T_L \quad (3)$$

where

$P_L$  = propagation path loss (db) which is equal to the absolute value of the difference between the receiver noise floor (dbm) and the effective radiated power of the tag, dbm

$S_L$  = signal loss across air/water interface, db

$A_2$  = signal loss through air, db (Equation 2)

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\* Determined by feeding a known signal strength (power) to the receiver input; that strength at which the signal is just audible is defined as the receiver noise floor.

$Y_G$  = gain of receiving antenna over a reference point source, db  
 $T_L$  = signal loss through the transmission line connecting the antenna and receiver, db

The unit attenuation of a radio signal traveling through water (computed from Equation 1 or measured in the field) is constant for a given electrical conductivity and temperature. Thus, knowing this constant, the tag depth (m) is:

$$D = \frac{A_w \text{ (db)}}{A_1 \text{ (db/m)}} \quad (4)$$

54. As an example, consider a fish at an unknown depth in Lake Conway whose tag radiates a signal at 49 MHz with a strength of -70 dbm. The mobile tracking unit is 40 m away from the estimated surface position of the tagged fish (a viewing angle of 5 deg; at this angle, the loss across the air/water interface is estimated to be 30 db); the gain of the dual Yagi antenna system on the mobile tracking unit is 13 db (peak position), with a 1-db loss in the transmission line between the antenna and receiver (noise floor is -135 dbm). The signal loss through air can be computed from Equation 2, as follows:

$$A_2 = 22 + 10 \log_{10} \left( \frac{40}{6} \right)^2 = 38 \text{ db}$$

Then, from Equation 3:

$$A_w = |-135 - (-70)| - 30 - 38 + 13 - 1 = 9 \text{ db}$$

The measured conductivity of the Lake Conway water at 49 MHz is 4 db/m. The estimated depth of the tagged fish can now be calculated from Equation 4:

$$D = \frac{9 \text{ db}}{4 \text{ db/m}} = 2.25 \text{ m}$$

55. Extensive tests to verify this approach were conducted at Lake Conway and WES; however, severe signal fading cast doubt over the validity of the depth estimates. Examination of the test data and the theory underlying the propagation of a radio signal through a two-medium path indicated that the fading was probably a result of one or more of the following:

- a. Scattering of the signal across the air/water interface. Note that the wavelength of a 49-MHz radio signal underwater is only 0.68 m, and thus could be comparable to the length of a surface wave slope.
- b. The estimate of signal attenuation across the air/water interface.
- c. Reflection of the tag signal from the lake bottom and subsequent propagation across the air/water interface at a location on the surface other than above the tag.

#### Estimation of Radiotag Depth Using an Underwater Receiving Antenna

56. Consideration of the fading problems noted above when estimating the depth of a radiotag with an above-water receiving antenna indicated that problems a and b could be eliminated by using a directional underwater antenna. Using this approach, the signal would not have to cross the air/water interface which would, hopefully, eliminate the fading problem. With this method, the underwater antenna would have to be constructed such that, when the array was rotated through the horizontal plane, the radiation pattern would respond correctly to the azimuth between the antenna and the radiotag. Then, assuming the antenna was oriented correctly in the horizontal plane in the direction of the tag, and the distance and vertical angle from the antenna to the tag could be determined, then the depth (m) of the tag could be estimated as follows (Figure 24):

$$D = D_1 + R \sin \theta \quad (5)$$

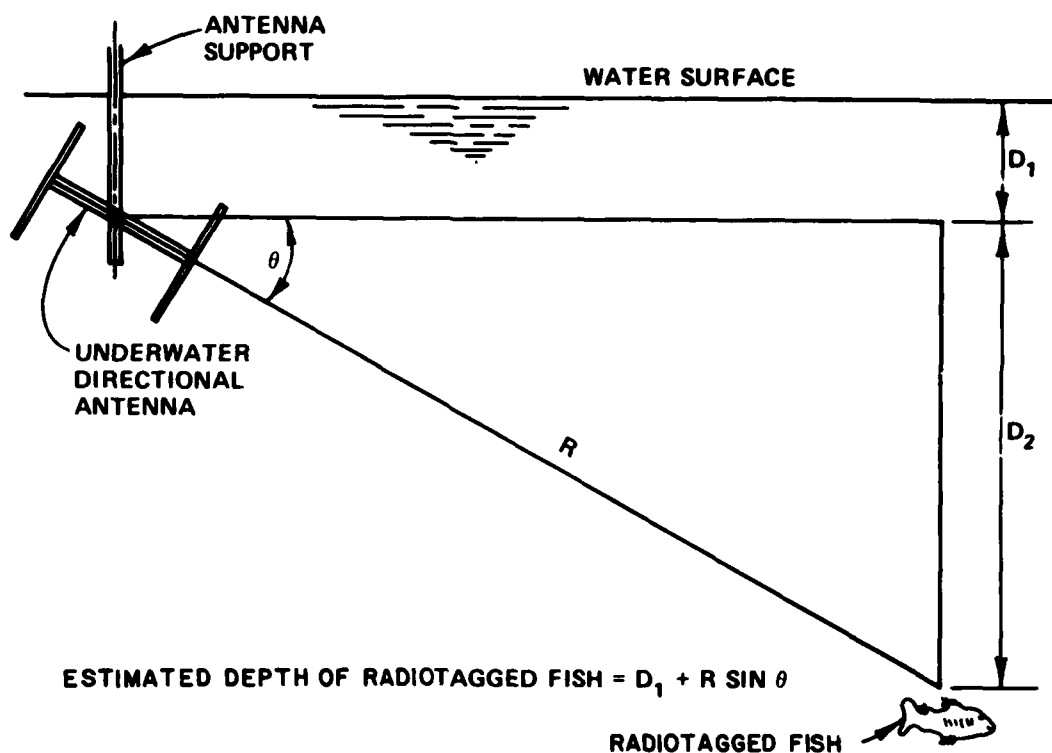


Figure 24. Estimation of radiotagged fish depth using an underwater antenna

where

$D_1$  = depth of the antenna below the water surface, m

$R$  = distance from the antenna to the tag, m

$\theta$  = included vertical angle between the horizontal and a line laid out along the axis of the antenna boom to the tag

57. Experiments were conducted at WES from February through September 1980 to evaluate the feasibility of this approach. Several directional antenna arrays were considered. A two-element driven dipole array was selected because of its relative insensitivity to element length, ease of electrical impedance matching, and simple mechanical construction (Figure 25). The antenna was fed with a Wilkinson Power Divider to minimize mutual coupling between the dipoles and to provide a 50-ohm impedance match to each dipole.

58. Both dipoles were made with insulated copper wire. Initial

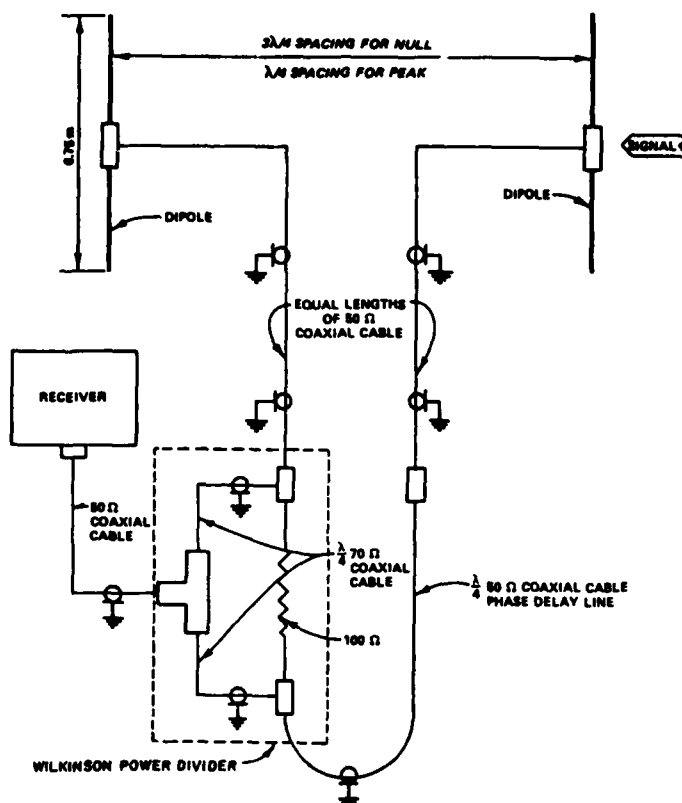


Figure 25. Schematic diagram of two-element driven dipole array fed by a Wilkinson Power Divider

tests with underwater bare-wire dipoles showed that the drive impedance was very low (less than 20 ohms);\* apparently, the conducting medium was shorting out the antenna. No problem was experienced in obtaining a 50-ohm drive impedance with an insulated dipole, although its length had to be determined experimentally. The resonant length  $L$  of a bare-wire dipole can be calculated from:

$$L = \frac{\lambda}{2\sqrt{\epsilon_r}} \quad (6)$$

\* Dipole impedances were estimated with a Palomar Engineers Noise Bridge and Yaesu FT-620B receiver (Figure 26). The length of the coaxial cable between the dipole feed point and the noise bridge was a multiple of one-half wavelength at the signal frequency (49.8 MHz).



Figure 26. Palomar Engineers Noise Bridge (left) and Yaesu FT-620B receiver used to estimate underwater dipole drive impedances. The battery used to power the receiver is on the right

At 49.8 MHz in 25°C water, this length is 0.33 m. Using number 14 insulated copper wire (with an insulation to wire diameter ratio of 2 to 1) to make the underwater dipoles, the resonant length was experimentally found to be 0.75 m. This length was found to be consistent with work done in 1963 (Ilzuka 1963).

59. The two-element array was constructed such that the dipoles could be spaced either one-quarter wavelength ( $\lambda/4$ ) apart or three-quarters wavelength ( $3\lambda/4$ ) apart. With the dipoles spaced  $\lambda/4$  apart and with a  $\lambda/4$  phase delay line in the feed line of the lead dipole (Figure 25) the signals fed to the receiver through the power divider are in phase (or additive), resulting in a radiation pattern that exhibits a peak in the direction of a signal source; i.e., as the antenna is rotated, maximum signal strength is realized at the receiver input when the incoming signal is perpendicular to the dipoles (Figure 25). When the dipoles are spaced  $3\lambda/4$  apart, the signals fed to the receiver are 180 deg out of phase, and a null results in the antenna radiation



pattern; i.e., when the elements are perpendicular to the incoming signal, the signal strength at the receiver input is a minimum.

60. Tests to evaluate the feasibility of estimating the depth of a radiotag with the two-element driven dipole array were conducted in a sump (11 × 28.5 m) made available by the WES Hydraulics Laboratory. During the evaluation period, the water temperature in the sump was 25°C, the depth 2.5 m, and the conductivity (DC) 300  $\mu$ mhos/cm.

61. The dipole array was initially tested to determine its angular resolution in the horizontal plane, i.e., to determine how accurately the angle between a reference azimuth and a line laid out from the antenna to a tag could be measured. With the dipoles spaced  $3\lambda/4$  apart (null in the antenna radiation pattern), the test results indicated that there was no significant error in estimating the azimuthal angle with the dipole elements perpendicular to the water surface; with the elements parallel to the surface, the radiation pattern was severely distorted.

62. The second step in the test sequence was to develop a procedure to estimate the distance between the dipole array and a radiotag, i.e., to obtain  $R$  in Equation 5. The dipoles were spaced  $\lambda/4$  apart to obtain a peak in the radiation pattern; the signal strength (db) of a tag at various distances between the antenna and the tag was then measured as referenced to the receiver noise floor.\* Four tags were used to make 250 measurements at distances between the antenna and tag of 2 to 13 m. The results were plotted on semilogarithmic paper and an error band was manually laid out around the cluster of data points. The upper and lower solid lines in Figure 27, which form the error band, represent the maximum and minimum spread of signal strengths measured at given distances between the antenna and tag. A dashed line was laid out on the plot midway between the upper and lower lines to represent a

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\* The gain of the antenna array was estimated to be 6 db above an isotropic source. The loss in the transmission line between the antenna array and receiver was 3 db; thus, 3 db was subtracted from the measurement of each signal strength above the receiver noise floor. The dipole elements were perpendicular to the water surface during these measurements.

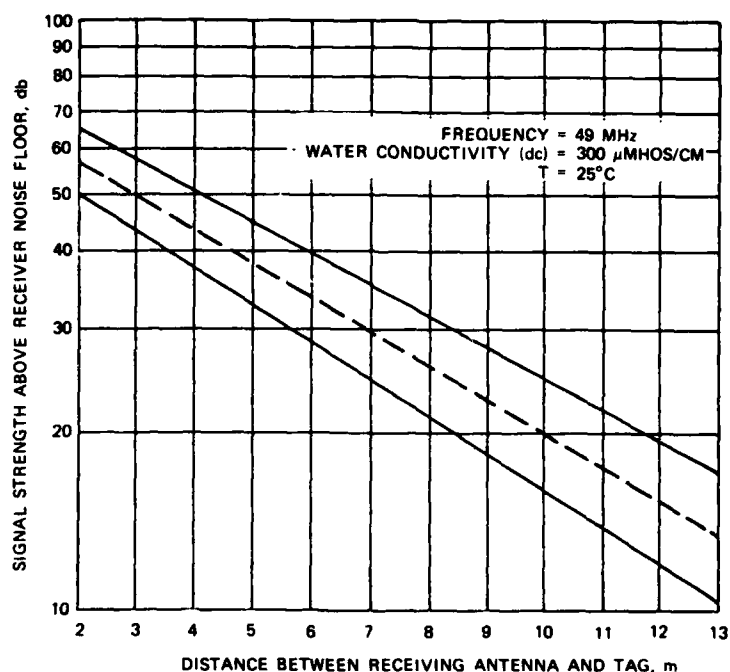


Figure 27. Graph to estimate distance between receiving antenna and radiotag as determined by measuring the tag's signal strength above the receiver noise floor. The effective radiated power of the AVM Instrument Company fish tags used to develop this graph was estimated to be less than -70 dbm

best estimate of the distance between the antenna and tag as determined by the tag signal strength above the receiver noise floor. Thus, if a signal is 50 db above the receiver noise floor, the distance between the antenna and tag can be estimated as 3 m (from dashed line in Figure 27); however, this value could vary  $\pm 1$  m as determined by the solid lines forming the error band. With a signal strength of 20 db above the noise floor, the distance estimate is 10 m; however, the potential error has increased to  $\pm 2$  m. Note that the distance between the antenna and tag in Figure 27 is limited to a range of 2 to 13 m. At distances of 2 m or less, the receiver experienced front-end overloading; beyond 13 m, signals were marginal in many cases, and measurements of tag signal

strengths above the receiver noise floor often became difficult due to slight fading.

63. The dipole array was adjusted to  $3\lambda/4$  spacing between the elements (null in the radiation pattern) to estimate the vertical angle, i.e., to obtain  $\theta$  in Equation 5. During this part of the test sequence, the antenna was supported by a structure made of polyvinyl chloride (PVC) pipe, whose nonconductive properties would not detune the antenna (Figures 28 and 29). The antenna was manually rotated from shore by a cable and counterweight assembly attached to the opposite end of the antenna boom (Figure 30). This assembly had a maximum error of 1 deg at angles  $\pm 15$  deg of the horizontal. Extensive testing with the antenna positioned near the water surface (Figure 31), at middepth, and near the bottom of the sump showed that errors in the vertical angle estimate up to 10 deg could be typically expected at distances of 8 to 13 m between the antenna and tag. At distances less than 8 m, the signals reflected from the air/water interface and from the concrete bottom of the sump distorted the radiation pattern of the antenna array; i.e., the null was no longer clearly detectable as the array was rotated through the vertical plane.

64. Thus, error in determining tag depth using this approach can result from a poor estimate of the distance between the antenna and tag and/or an error in estimating the vertical angle. As an example of the magnitude of the resulting error (at vertical angles  $\pm 15$  deg of the horizontal), consider a tag located 10 m from the antenna at an angle of 5 deg below the horizontal with the antenna located 1 m below the water surface. According to Equation 5, the depth of the tag would be 1.87 m. If the range can be estimated no better than  $\pm 2$  m, then  $R$  in Equation 5 could vary from 8 to 12 m. Equation 5 would then predict that the tag depth would be 1.70 or 2.05 m (with  $D_1 = 1$  m and  $\theta = 5$  deg). If the error in the vertical angle is 5 deg, then  $\theta$  in Equation 5 (with  $D = 1$  m and  $R = 10$  m) could vary from 0 to 10 deg; the depth estimate would then vary from 1.0 to 2.74 m. Obviously, greater error is introduced into the depth estimate due to the error in determining

Figure 28. PVC pipe structure used to support antenna array during tests to estimate the vertical angle  $\theta$  (Equation 5)



Figure 29. Two-element driven dipole array on rotating member of PVC pipe support structure



Figure 30. The dipole array was rotated through the vertical plane using a cable and counterweight assembly. The counterweight and attached cable are shown on the left end of the antenna boom with the dipole array on the right end



Figure 31. PVC pipe support structure in sump; the two-element driven dipole array is visible near the water surface

the vertical angle than in estimating the distance between the antenna and tag (for vertical angles close to the horizontal).

## PART VII: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

65. Documentation describing the effectiveness of the white amur as an environmentally compatible aquatic plant control method and a report assessing the impact of the amur on the Lake Conway herpetofaunal community are in preparation at this time. Although the data collection and evaluation phases of these two efforts have not been completed at this writing, some generalized conclusions and recommendations can be made regarding the use of radiotelemetry as a support technique to meet the overall objectives of the Lake Conway LSOMT.

66. The radiotelemetry tracking system developed by WES has sufficient resolution to precisely determine the surface location of an underwater tagged individual.

67. Experiments to develop a system to estimate the depth of an underwater tagged individual have been marginally successful. The system is not practical for field use due to the limited working range between the antenna and tag and due to the error in estimating the vertical angle; however, the testing at WES has shown that this approach may be a practical method to determine the depth of a radiotag. A survey of available literature (Appendix B) indicates that this application was the first attempt to use a conventional directional antenna array in an underwater environment for tracking purposes.

### Recommendations

68. Although the methodology to locate the surface position of a tagged individual is relatively straightforward, a technique to estimate depth is not. Additional research is needed before such a technique could be made available for routine field use.

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APPENDIX A: LITERATURE SURVEY FOR TRACKING AQUATIC ANIMALS  
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APPENDIX B: LITERATURE SURVEY FOR TRACKING AQUATIC ANIMALS  
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